

Technology Planning for NASA's Future Planetary Science Missions

Patricia Beauchamp

Jet Propulsion Laboratory, California Institute of Technology

Carolyn Mercer

NASA Glenn Research Center

Leonard Dudzinski

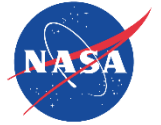
NASA HQ – Planetary Science Division



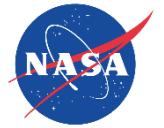
Setting the Stage

- Science Mission development, implementation and funding sources are different within the USA and Europe.
 - NASA funds mission and instrument concepts, development, implementation and operations. Partnerships with industry exist.
 - ESA funds mission formulation and development, which is implemented - from concept through flight-build - by industry. Operations are funded and carried out by ESA
 - Nations fund instrument concepts, development, instrument operations, data analysis and archiving
- Development of Technologies in Europe and the USA follow different paths
 - NASA funds and develops many of the Technologies and test facilities but some early instrument development done in academia/industry. Industry does Tech. development under their own IR&D, with some NASA support.
 - In Europe, industry does much of the development, in large part funded by ESA through different technology development programs, with national agencies augmenting both with funding and development, especially for instruments

Historical Perspective



- NASA HQ has managed Technology programs in a variety of ways
 - ~1960's – Technology was focused on achieving specific goals, and augmented with a Sustaining University Program
 - ~1970's – ~1990's: Technology development was conducted at each Center, with local decision making, under "Code R"
 - Early 2000's, competition-based funding for technology began
 - Early 2010's created the Space Technology Mission Directorate (STMD) to develop technologies for Human Exploration *and* Science Missions
 - FY19 Budget proposes to focus STMD on Human Exploration needs. Science technology development would continue in the Science Mission Directorate.
- Within Planetary Science Division, Technology programs have been intermittent
 - Mars Technology program vigorous since inception of Mars Program; may be decreasing
 - Solar system -- Technology investments focus on Instruments, Propulsion and Radioisotope Power, with recent investments in electronics, power, and mechanisms for very hot and very cold environments
- *Visions and Voyages* and NASA Planetary Science Technology Review Panel helped invigorate a renewed focus on Technology



Visions and Voyages

“The committee unequivocally recommends that a substantial program of planetary exploration technology development should be reconstituted and carefully protected against all incursions that would deplete its resources. This program should be consistently funded at approximately 6 to 8 percent of the total NASA Planetary Science Division budget.”

“The committee recommends that the Planetary Science Division’s technology program should accept the responsibility, and assign the required funds, to continue the development of **the most important technology items** through TRL 6.”

Goal of Planetary Science Technology Review (PSTR) panel

- The primary purpose of the Planetary Science Technology Review (PSTR) panel was:
 - to assist the Planetary Science Division (PSD) of NASA Headquarters in developing a coordinated and integrated technology development plan that will better utilize technology resources
- The panel will suggest process and policy changes
 - help answer the '**how**' questions
- The panel relied on the planetary decadal survey, *Visions and Voyages*, to identify **what** technologies PSD should invest in

PSTR Major Recommendations (2011)

Management	
M1) Establish a dedicated (Dir.) position with overall responsibility for PSD technology	✓
M2) Establish a small supporting program office	✓
Strategy	
M3) Develop a comprehensive strategy for PSD technology	✓
M4) Suggested Resource Allocation Strategy	✓
M5) Actively pursue a strategy of leveraging opportunities within and outside NASA	✓
Process	
M6) Develop a more consistent and accurate TRL assessment process	✓
M7) Develop clear, transparent, and consistent decision and review processes	✓
M8) Develop a more structured and rigorous process to create interactions between technologists, scientists and missions	✓
Culture and Communication	
M9) Develop an overall communication plan and technology database	✓
M10) Foster a culture advocating for and defending technology	✓
Resources	
M11) Support Decadal Survey comments on importance of technology funding. PSTR recommends stable funding at the higher end of the decadal suggested range - 8%	✓
<div> <div>✓ Completed</div> <div>✓ In Progress</div> <div>✓ Partially Initiated</div> </div>	



M6) Develop a more consistent and accurate TRL assessment process

2014-15 NASA OCT/OCE/Centers Team Focus Areas

The team addressed the following areas based on the data collected through the information gathering process

TRL

Definitions

TRL progression and exit criteria

Uses and applications of TRL

Guidelines for proposal calls

Guidance on utilizing and interpreting TRL scale

TRL roll-up

Training/education on readiness levels

Tools

Software readiness levels

TRA

Readiness assessment process

Identifying technologies (new technology, engineering, or heritage)

Uses and applications of assessment results

Guidance on conducting assessments

Independent Assessments

Development Difficulty/Risk

Training/education on conducting assessment and using results

Tools

Software assessments

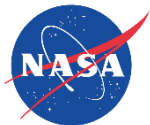
Other readiness levels



Developed updated TRL definitions and a Technology Readiness Assessment process

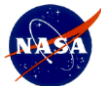
TRL	Definition from NPR 7123.1e	Completion Criteria from NPR 7123.1e	Mission Req.	Performance/ Function	Fidelity of Analysis	Fidelity of Build	Level of Integration	Environment Verification
6	System/ subsystem model or prototype demonstrated in a relevant environment	Documented test performance demonstrating agreement with analytical predictions	Specific mission	Required functionality/ performance demonstrated	Medium fidelity: to predict key performance parameters and life limiting factors as a function of operational environments	High fidelity: prototype that addresses all critical scaling issues	Subsystem/ System	Tested in relevant environments. Verify by test that the technology is resilient to the effects of life-limiting mechanisms

Ref: JPL Technology Readiness Assessment Guideline
M.A. Frerking, P. M. Beauchamp, IEEE Aerospace Conference Proceedings, 2016

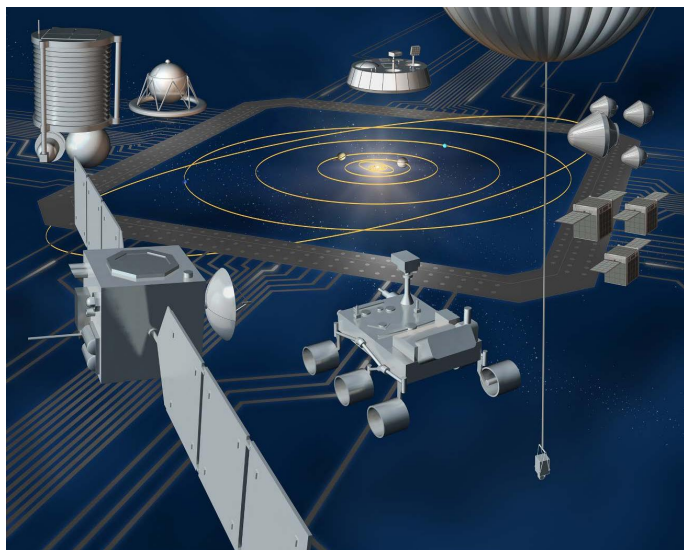


M3) Develop a comprehensive strategy for PSD technology

In parallel, developed a PSD Technology Plan



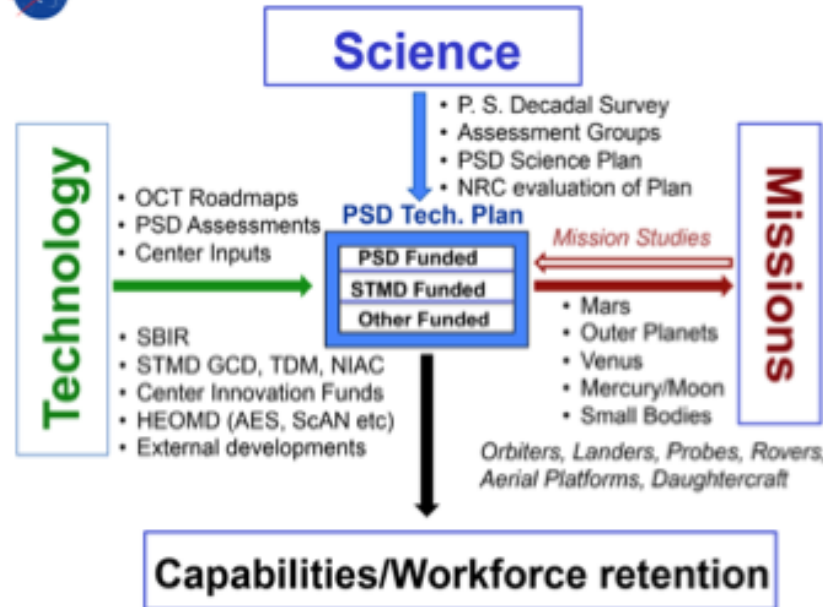
NASA Planetary Science Division Technology Plan



December 20, 2015



Schematic of PSD Technology Plan





Community Technology Inputs

(VEXAG, OPAG, SBAG, Mars Program, Decadal, Surveys)
from: Planetary Science Technology Plan, April 9, 2015

		This decadal					Next decadal					After that				
		NEAR TERM MISSIONS					MID TERM MISSIONS					FAR TERM MISSIONS				
Applicable Technology		Small Bodies	Outer Planets	Venus	Mars	Moon	Small Bodies	Outer Planets	Venus	Mars	Moon	Small Bodies	Outer Planets	Venus	Mars	Moon
SYSTEM TECHNOLOGIES	In Space Propulsion															
	Aerocapture/Aeroassist															
	Entry (including at Earth)															
	Descent and Deployment															
	Landing at target object															
	Aerial Platforms															
	Landers - Short Duration															
	Landers - Long Duration															
	Mobile platform - surface, near surface															
	Ascent Vehicle															
	Sample Return															
	Planetary Protection															
SUBSYSTEM TECHNOLOGIES	Energy Storage - Batteries															
	Power Generation - Solar															
	Power Generation - RPS															
	Thermal Control - Passive															
	Thermal Control - Active															
	Rad Hard Electronics															
	Extreme Temp Mechanisms															
	Extreme Temp Electronics															
	Communications															
	Autonomous Operations															
	GN&C															
INSTRUMENT	Remote Sensing - Active															
	Remote Sensing - Passive															
	Probe - Aerial Platform															
	In Situ - Space Physics															
	In Situ Surface - Geophysical															
	Sampling															
	In Situ Surface - Long Duration - Mobile															

	TRL 6 and above						
	High TRL - limited development and testing needed						
	Moderate TRL - major R&D needed						
	Low TRL - notable technical challenges						



2017 - Planetary Exploration Science Technology Office (PESTO)

New HQ office (located at GRC) to:

Recommend technology investment strategy for future planetary science missions

- Instruments
- Spacecraft Technology
- Mission Support Technology

Manage PSD technology development (non-mission specific, non-nuclear)

- PICASSO, MatISSE, HOTTech, COLDTech, DALI, ...

Coordinate planetary science-relevant technologies

- Within the Planetary Science Division, Science Mission Directorate, and Space Technology Mission Directorate, ...

Promote technology infusion

- Infusion starts before solicitations are written, ends with mission adoption

Technology Investment Goal: Per the Decadal, 6-8% of Planetary Science Division budget
\$110-150M per year for technology, excluding infrastructure investments or sustainment



Planetary Exploration Science Technology Office (PESTO)

Investment Strategy

- Identified high priority technologies
- Quantifying Technology Goals, State-of-the-Art, and Science Case for each high priority tech
- Writing Investment Strategies for each
- Conducting Technology Reviews
- Assessing Technology Development Costs

Coordination

- Earth Science, Heliophysics, Astrophysics
- STMD Programs
 - SBIR/STTR
 - Early Stage Innovation
 - Space Technology Research Institute
 - Small Spacecraft
 - Game Changing Development
- Human Exploration and Operations Mission Directorate

Management

- **PICASSO** – low-TRL Instruments
- **MatISSE** – mid-TRL Instruments
- **DALI** – Lunar Instruments
- **COLDTech & Icy Satellites** – Instruments & Spacecraft Technology for Ocean Worlds
- **HOTTech** – Venus spacecraft technology

Infusion

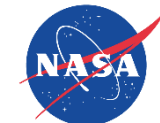
- Focus Solicitations
 - Infusion begins before it is written
- Infusion Mentors Bring
 - flight perspective early on
- Workshops
- TRL Assessment / Advancement
- Communication



How to determine “the most important technology items”?

- Planetary Technology Working Group Members re-surveyed the VEXAG, OPAG, SBAG, Mars Program, and the Decadal Survey
- Then assessed each technology identified by the AGs using the following Figures of Merit:
 - Critical Technology for Future Mission(s) of Interest
 - Degree of Applicability across PSD Missions/needs
 - Work Required to Complete
 - Opportunity for Cost Sharing
 - Likelihood of Successful Development and Infusion
 - Commercial Sustainability
- Corporate knowledge includes previous studies, e.g.:
 - “PSD Relevant Technologies,” G. Johnston 1/7/2011
 - “Planetary Science Technology Review Panel – Final Report,” T. Kremic, 7/29/2011
 - “Planetary Science Division Technology Plan,” P. Beauchamp, 12/20/2015

Planetary Science Division High Priority Technologies



Planetary Technologies

- Electronics (high temperature)
- Communications (high bandwidth, high data rate)
- Solar Power (low intensity, low temp)
- Power Systems (high temperature)
- RPS surface power
- RPS orbital power
- System autonomy (GNC, Prox Ops, C&DH, sampling ops, FDIR)
- Small Spacecraft Power, GNC, Propulsion, Comm
- Planetary Ascent Vehicle for Sample Return
- Heat Shield technologies for planetary entry and sample return
- Computing and FPGAs (high performance/low power/rad hard)

Instruments

- Life Detection for Ocean Worlds
- Low mass, low power instruments for cold, high rad ocean world environments
- Low mass, low power instruments for SmallSats

Ocean Worlds

- Electronics (low temp, low power, rad-hard)
- Actuators/mechanisms (low temp)
- Planetary Protection Techniques/component and material compatibility
- Ice Acquisition and Handling (>0.2 m depth)
- Ice Sample Return
- Pinpoint Landing on Titan

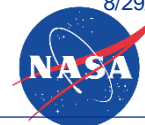
Europa

- Ice Acquisition and Handling (surface, cryo)
- Batteries (low temp)
- Pinpoint Landing on Europa
- Landing Hazard Avoidance



Planetary Technologies

- **High-Temperature Compatible Electronics**
- **High Bandwidth, High Data Rate Communications**
 - Large Deployable Reflectors and High Power TWTs
- **Low Intensity/Low Temperature Solar Power**
- **High-Temperature Compatible Power Systems**
 - Batteries
 - Power Generation
 - Low-Intensity High-Temperature Solar Cells
- **RPS Power**
 - Orbital and Surface: Radioisotope Thermoelectric Generator – eMMRTG
 - Orbital: Radioisotope Thermoelectric Generator - Next Gen RTG
 - Orbital and Surface: Dynamic RPS
- **System Autonomy**
 - Autonomous Navigation for EDL
 - Reactive Science Autonomy
 - Efficient Planetary Surface Science Ops
- **Small Spacecraft**
 - Propulsion – Electric & Non-Toxic Chem
 - Power, GNC,& Communications
- **Planetary Ascent Vehicle for Sample Return - Mars Ascent Vehicle**
- **Heat Shield Technologies for Planetary Entry and Sample Return**
 - Thermal Protection Systems
 - Aerocapture
- **High performance/low power/rad hard computing and FPGAs**
 - Chiplet Augmentation, Advanced Space Memory, Co-Processors/Accelerators, System Software, Development Environment, Power, Computer



Ice Penetration and Sampling –Low-Mass, Low-Power Excavation

Technical Goal

Establish one or more methods to extract samples from ice (with possible salts, sulfur and biomolecules) in Ocean Worlds at progressively increasing depths, eventually all the way to the liquid water:

- Pristine as possible (at least at micro-scale)
- Reduce cross-contamination
- Must tolerate sulfur-rich environment (e.g. H_2SO_4)

Landed missions expected to have saws, drills, melt-probes, etc. deployed from within the lander body onto or into the ice.

Technical Status

- Europa lander study has conducted many expts of cutting cryogenic ice, mostly with saws.
- 3D-printed 316 stainless saw blade has cut -85C ice.
- Many approaches exist for sampling between 0.2m & 2m: circular or chain saws, heated blades or scoops
- Wireline drills allow open-hole drilling or coring without lining the hole in formations where mechanical properties allow a hole to remain open without lining.
- Novel approaches to melt probes (e.g. putting heat source in Dewar to eliminate horizontal heat leak) may allow deep penetration within M/P/V limits.

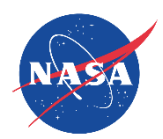
Ice Penetration and Sampling – Sample Handling and Transport

Technical Goal

- Develop process for sample handling and hardware transport system for samples from the point of extraction taking into account:
 - forward contamination constraints,
 - ensuring Earth life is not ingested into instruments
 - specific sample preparation requirements for each instrument.
 - method to handoff sample to instrument or SR

Technical Status

- Sample handling and transport has not been attempted at cryogenic temperatures by robotic spacecraft.
- Biomolecule detection may be done at liquid water temperatures, so cryogenic handling may not be required for all (or any) instruments.



Heat Shield Technologies for Planetary Entry and Sample Return— Thermal Protection Systems

10/9/17

Technical Goal

Thermal Protection Systems (TPS) and integrated entry vehicle system technologies are required to accomplish missions at the most challenging destinations in the Solar System. TPS and entry vehicle technologies are also required for high-speed Earth return of samples from various Solar System bodies such as comets, asteroids, moons, and other planets.

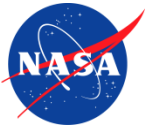
1. Peak heating rates of $\sim 5000 \text{ W/cm}^2$ & pressures in excess of 5 atmospheres
2. Entry system mass fractions less than 30-40% for trajectories limiting payload structural loads to 10-50 g's.
3. Reliable ($<10^6$ chance of failure) entry systems for biological sample return.

Technical Status

- **Earth Return: PICA.** Heritage PICA (Stardust, OSIRIS-REx, MSL, Mars2020) no longer sustainable due to discontinued rayon manufacturing.
 - Stardust (0.83 m monolithic PICA TPS; 12.6 km/s, 1200 W/cm^2 peak).
- **Venus:** Previous carbon phenolic (CP) heatshields (e.g. Galileo) had mass fractions in excess of 50% resulting in trajectories subjecting the payloads > 300 of g's. CP is no longer supported by the supply chain.
 - Pioneer (0.76-1.42 m carbon phenolic; 11.5 km/s, $3900\text{-}5500 \text{ W/cm}^2$)
- EDL systems must be sufficiently instrumented to provide the data required to effectively model the Discovery and New Frontiers AO's. The Mars 2020 heatshield and backshell include engineering sensors to collect temperature, heat flux, radiation, and pressure data.

Mission Applications

- Technology maturation is enabling for Venus, Saturn, Uranus, Neptune, & Ocean World missions concepts.
- Reduced entry system mass will reduce launch and qualification costs Venus, Saturn, Discovery, and New Frontiers missions.
- Highly robust Entry system technologies will enable the high-speed Earth return of potentially biologically-active samples.
- Improved validated modeling techniques will reduce design margins, better quantify risk, and certify entry systems for all NASA missions.



Summary

- NASA Planetary Science Division:
 - has taken steps to plan Technologies for future mission concepts
 - has a Technology Office, PESTO, to focus on needs
 - is completing the development of frameworks to manage the technology planning, development and infusion
 - is developing technologies to withstand harsh mission environments
 - Stresses communication between communities and Centers with respect to TRL, risk and technology infusion
- Planetary missions are highly dynamic
 - competitive nature of the process
 - heavily dependent on the federal budget process.
- Technology Planning has to be dynamic to match the world we live in.
- Focus on infusion of Technologies into mission concepts.